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Case Studies: A Tracer Gas Evaluation at a Garment Manufacturing Facility with Extensive Transmission of Tuberculosis

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Case Studies

A Tracer Gas Evaluation at a Garment Manufacturing Facility with Extensive Transmission of Tuberculosis

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Reported by Teresa Seitz, Vince Mortimer, and Kenneth Martinez

Introduction

In May 1995, an employee at a garment manufacturing facility, located in a rural community, was diagnosed with cavitary tuberculosis (TB). Because the initial contact investigation of family and friends identified a large number of persons with positive tuberculin skin tests (TSTs) (indicating infection with *Mycobacterium tuberculosis*, the bacteria that causes TB), the investigation was extended to all co-workers at the plant. In June 1995, the Division of Tuberculosis Elimination (DTBE), National Center for HIV, STD, and TB Prevention (NCHSTP), Centers for Disease Control and Prevention (CDC), was asked to assist the state and local health departments with the investigation. TST screening identified positive skin tests among 75 percent of the work force (174 of 233 workers tested), with documented TST conversions among 30 (17%) workers.[1]

In July 1995, the DTBE, NCHSTP, requested assistance from the National Institute for Occupational Safety and Health (NIOSH) in evaluating the ventilation system at the plant. NIOSH investigators performed an initial evaluation to measure air flow rates and assess air movement within the plant. Because of the unusually high number of positive skin tests found among the employees, a more in-depth ventilation assessment was made to document conditions that probably occurred during the period of time the employee with TB was infectious. This involved a tracer gas evaluation to quantify the extent and speed of contaminant dispersion and contaminant removal rate. Sulfur hexafluoride was used as the tracer.

Background

TB is an infectious disease caused by *Mycobacterium tuberculosis*. The bacteria are carried in airborne particles known as droplet nuclei, which can be generated when persons with pulmonary or laryngeal TB cough, sneeze, or vocalize.[2] Because of their small size (1 to 5 μm), the droplet nuclei can be suspended in the air for long periods of time, probably hours. Infection occurs when a susceptible person inhales infectious droplet nuclei and the particles become established in the alveoli of the lungs and spread throughout the body. Within 2 to 10 weeks, the body's immune system is usually able to prevent further multiplication and spread of bacteria; however, some of the organisms might remain dormant, but viable, for many years. People with this condition, referred to as latent TB infection, will usually test positive on a purified protein derivative TST, but will not have symptoms of active TB and are not infectious. Individuals with latent TB infection have approximately a 10 percent risk of developing active TB in their lifetimes, with the risk being greater for persons who are immunocompromised.[3] To decrease the chance of developing active disease, CDC recommends that persons with positive TSTs be evaluated for preventive drug therapy.[4]

The probability that a person exposed to *M. tuberculosis* will become infected depends primarily on the concentration of infectious droplet nuclei in the air and the duration of exposure. The actual dose required to initiate infection is not known. The probability of TB transmission is affected by the number of infectious persons and their level of infectiousness, the susceptibility and proximity of uninfected individuals, and the building ventilation.

Ventilation guidelines for the prevention of TB transmission in industrial environments do not exist. Ventilation is present in most buildings to maintain a comfortable environment by providing a supply of air which may be heated or cooled, and humidified or dehumidified. Another function of ventilation is to bring in fresh air and exhaust airborne contaminants. Usually, the flow of supplied air also creates air currents which substantially mix the air in an enclosed space before it is exhausted. Because TB is spread by airborne bacteria, ventilation is a factor in the spread of this infection. Both the extent and rapidity of the spread of contaminants and their rate of removal are important. In this evaluation we assessed the spread and removal of a tracer gas that was used as a surrogate for the contaminant, *M. tuberculosis*.

Process Description

At the time of the NIOSH evaluation there were approximately 263 workers at the plant. This included 238 sewers and 25 staff personnel, 7 of whom worked directly in the warehouse. The plant hours are from 7:00 a.m. to 4:30 p.m. Monday through Thursday, and 7:00 to 11:00 a.m. on Friday. Additional hours are scheduled on Friday and Saturday as needed to meet production demands. About 75,000 knit jerseys are produced each week at this facility from precut cotton and polyester/cotton blended fabrics. A Gerber fabric mover system is used to facilitate garment manufacture.

Methods

Preliminary Ventilation Assessment

NIOSH investigators performed a walk-through survey and a preliminary ventilation system evaluation to assess the potential for dissemination of airborne *M. tuberculosis*. The ventilation system evaluation included discussions with persons responsible for operation and maintenance of the system and performance of air flow measurements.

Air flow measurements were made at

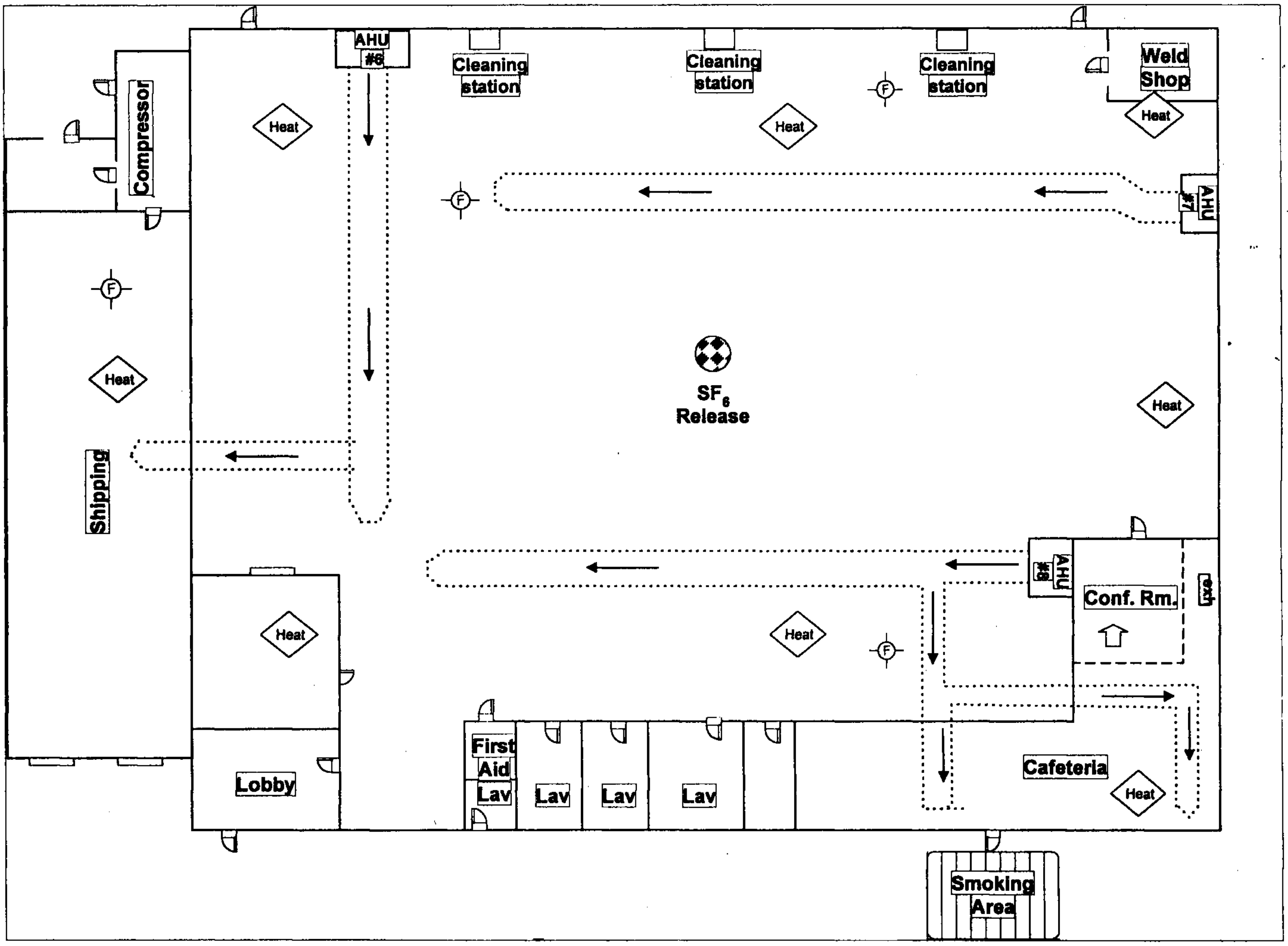

FIGURE 1. Floor plan and layout.

the outside air intakes and exhaust and return air locations using either a TSI model 8360 VelociCalc Plus thermoanemometer or TSI model 8370 AccuBalance flow measuring hood (TSI Inc., St. Paul, Minnesota). The choice of instrument was dependent on the inlet or outlet configuration. The flow hood provides air flow rate data directly in cubic feet per minute. When the thermoanemometer was used, a traverse was made and multiple air velocity measurements were taken at the face of the grille. The average air velocity was then used to calculate the air flow rate by multiplying the air velocity by the area of the opening.

Tracer Gas Evaluation

A tracer gas evaluation was conducted to quantify the extent and speed of contam-

TABLE 1. Air Flow Measurements

Source	Supply Air (ft^3/min)	Outside Air (ft^3/min)	Exhaust Air (ft^3/min)
AHU 6	4353	2655	
AHU 7	3086	1260	
AHU 8	8740	None	
Exhaust fan (near conference room)			1690
Compressor room			465[A]
Women's lavatory			87
Men's lavatory			105
Handicap lavatory			70
First aid room			50
Utility room			60
Canopy hood (welding area)			365
Cafeteria (three supplemental exhaust fans combined)			310
Cleaning stations (three stations combined)			588

[A]Indirect measurement of air entering through doorway.

inant dispersion and contaminant removal rate. Sulfur hexafluoride, a colorless, odorless gas was used as the tracer because it is chemically and toxicologically inert,[5,6] and there would be no other sources in the plant. Target concentrations of this tracer gas are typically in the range of 1 to 10 ppm, well below the time-weighted average exposure limits for sulfur hexafluoride of 1000 ppm.[7–9] Sulfur hexafluoride has been shown to be an acceptable surrogate for the movement of *M. tuberculosis* bacteria in air.[10] Taking into account normal room air currents and size distribution, the droplet nuclei and tracer gas will remain suspended and follow essentially the same path in moving air.[11]

Pure sulfur hexafluoride was released at a controlled rate from a location in the middle of the production area (see Figure 1). The release time was 7 minutes, with a target sulfur hexafluoride concentration of 3 ppm. Sulfur hexafluoride was then detected at selected locations in the plant using one of two instruments: an infrared monitor or a photoacoustic analyzer. Five infrared monitors were used. All were MIRAN-203 continuous flow, infrared gas analyzers with interchangeable filters (The Foxboro Company, East Bridgewater, Massachusetts). The filter used for sulfur hexafluoride selectively passed infrared light with a wavelength of 10.6 μm. At a path length of 12.5 m, sulfur hexafluoride could be monitored in the range of 0 to 4 ppm. Although the system was factory calibrated, the voltage output of each instrument was correlated with the actual test room concentration of sulfur hexafluoride as measured with one of the photoacoustic analyzers prior to the survey.

Three photoacoustic analyzers were also used to determine the concentration of sulfur hexafluoride at selected locations in the plant. All were B&K-1302 periodic sampling gas analyzers (Brüel & Kjaer Instruments, Inc., Marlborough, Massachusetts). Each instrument was fitted with a narrow-bandwidth, 10.6-μm filter for sulfur hexafluoride and a separate filter to measure and/or correct for the effect of water vapor (relative humidity) in the sampled air. The B&K instruments were calibrated by the manufacturer.

The instruments were placed in selected locations for the duration of a test, which lasted about 5 hours. Tests were conducted during January 30 and 31, 1996. Sulfur hexafluoride injections were made in the morning and afternoon. The sulfur hexafluoride concentrations measured by the instruments were stored in computer memory and analyzed after the survey. Plots of the natural log of concentration versus time were made, and a straight line that best fit the data was generated using mathematical regression analysis. The slope of the line is equivalent to the air change rate.

Results

Preliminary Ventilation Assessment

A floor plan of the facility is shown in Figure 1. The main section of the plant is approximately 140 by 200 ft, and the shipping area is about 40 by 80 ft. The locations of the ceiling fans, heaters, air handling units (AHUs), and associated ductwork are shown in the figure. There are no return air ducts for these AHUs; return air enters the AHUs through the front of the units after passing through aluminum and/or polyester/fiberglass particulate filters. The AHUs provide cooling only. Heating is provided by gas-fired heaters suspended from the ceiling. The AHU fans remain on during the heating season to improve air circulation within the plant. To provide optimum conditions for sewing knit fabrics, the relative humidity is maintained between 50 and 55 percent through the use of a misting system located above the workstations. During the cooling season, inside temperatures are maintained around 72° to 73°F, and during the heating season at 68° to 70°F. The four ceiling-

TABLE 2. Response Times for Detection of the Sulfur Hexafluoride Tracer Gas

	Response Time (minutes:seconds)							
Day/Conditions	**AHU 6**	**AHU 7**	**AHU 8**	**Cafeteria**	**Loading Dock**	**Corner Outside Office/ Lobby**	**Between Movers 1 and 2**	**Between Movers 2 and 3**
1/30/96								
Injection at 6:51 a.m.; circulating fans off; AHU 6 no outside air	01:40	—	03:00	N/A[A]	07:10	—	02:51	03:11
1/30/96								
Injection at 12:00 p.m.; circulating fans on at 12: 10 p.m.; AHU 6 no outside air	02:35	—	08:00	07:35	10:55	—	03:01	06:35
1/31/96								
Injection at 7:03 a.m.; circulating fans on; AHU 6 open for outside air	03:00	04:55	03:30	—	—	03:15	02:17	02:55
1/31/96								
Injection at 12:10 p.m.; circulating fans on; AHU 6 open for outside air	07:40	10:25	08:10	—	—	08:05	06:23	07:19

[A]N/A = not available; equipment failure.

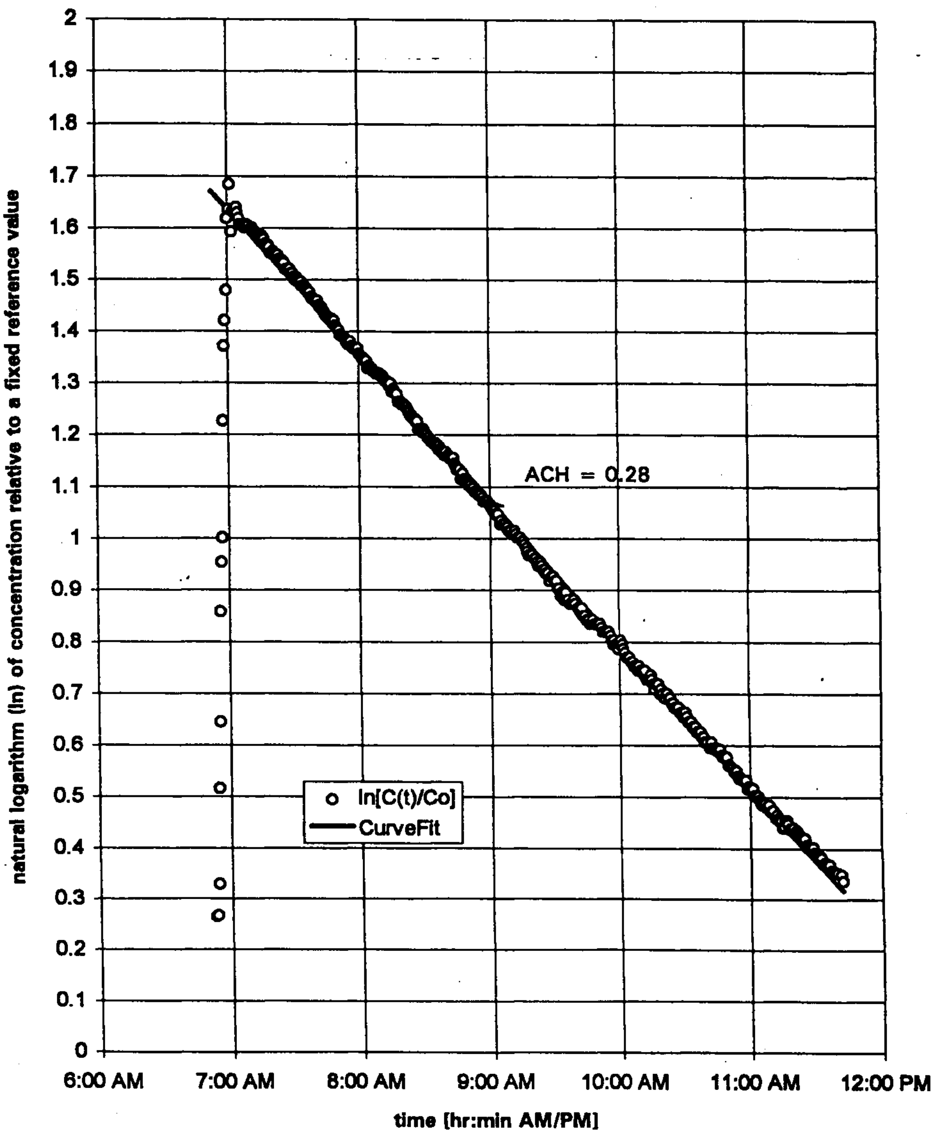

FIGURE 2. A typical concentration–decay plot. The slope of the line is equal to the air change rate.

mounted fans were not consistently used during the evaluation.

Air mixing between the office and plant areas occurs due to their close proximity and the frequent opening of doors. AHUs 6 and 7 have the capability of supplying outside air, while AHU 8 does not. On the days of the NIOSH evaluation, the outside air intake for AHU 7 was open. As shown in Table 1, 1260 ft^3/min of outside air was supplied by this unit. The damper for AHU 6 was not open during the survey because it was connected to the energy management system, which reportedly would only bring in outside air when outdoor temperatures (during the cooling season) were below 74°F. However, we were able to manually override the system to make air flow measurements. With the damper fully open, the unit was bringing in 2655 ft^3/min of outside air. The energy management system also controls an exhaust fan located on the outer wall behind the upstairs conference room. This exhaust fan operates in conjunction with the outside air damper for AHU 6. With the system in the override mode, this fan was exhausting approximately 1690 ft^3/min of air. Assuming that outside air dampers for AHUs 6 and 7 are fully open, bringing in a total of 3915 ft^3/min of outside air (approximately 15 ft^3/min of outside air per person) and a plant volume of 650,000 ft^3, this equates to an air change rate of approximately 0.36 air changes per hour (ACH).

Tracer Gas Evaluation

As shown in Table 2, the tracer gas spread quickly throughout the plant, never requiring more than 11 minutes to reach even the locations farthest from the release point (approximately 100 ft away). On one occasion, sulfur hexafluoride reached the intake to AHU 6 in less than 2 minutes. The response times varied considerably between tests for any given location. This may be due to a number of factors that were not evaluated, including production line operation, temperature gradients in the plant, and heating unit operation.

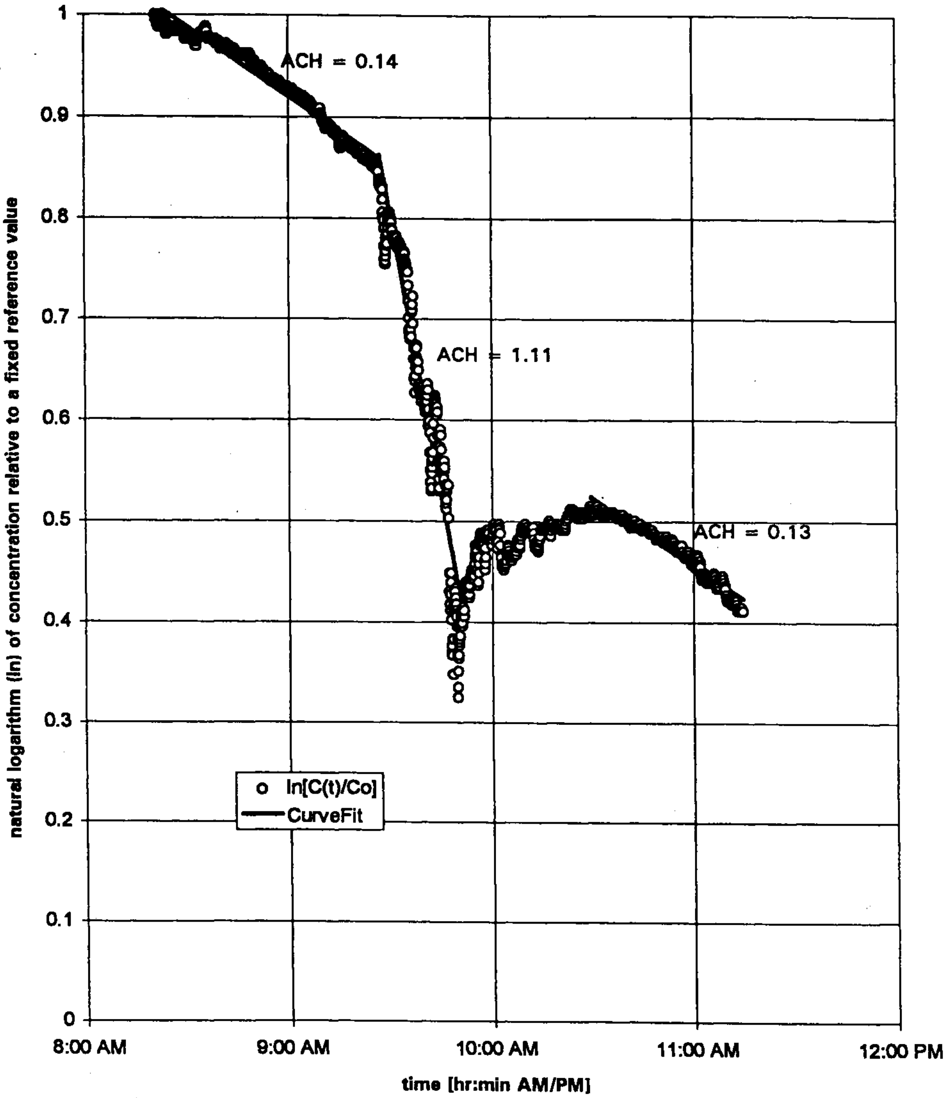

FIGURE 3. Concentration–decay plot for the cafeteria showing ventilation rate changes during breaks.

Sulfur hexafluoride was spread uniformly throughout the plant. The concentration of sulfur hexafluoride measured at stationary sampling locations equilibrated within about 30 minutes, with the exception of the cafeteria and the loading dock, which took about 1 hour. Sulfur hexafluoride was also detected in nonproduction areas such as the engineering office, main office, and cafeteria; however, in the main office the concentrations rose much more slowly. For example, on the first day of measurement, the sulfur hexafluoride concentration in the main office was 1.1 ppm approximately 50 minutes after the injection, while the concentration in the adjacent lobby area was 2.4 ppm.

Sulfur hexafluoride was slowly removed from the plant. When the production line was operating, more than 2 hours were required for the sulfur hexafluoride concentration to be reduced by half. Figure 2 shows a typical contaminant decay curve. The slope of the line, noted on the graph as the ACH value, is representative of the ventilation rate. To calculate the actual flow rate in cubic feet per minute, the ACH value is multiplied by the volume of the plant (approximately 650,000 ft^3) and divided by 60 to convert the time units from hours to minutes.

In the cafeteria, over 4 hours would have been required to halve the sulfur hexafluoride concentration if there hadn't been an exodus outside during break times. Figure 3 shows that when people were moving through the cafeteria to and from the smoking area outside the building, the effective rate of ventilation in the cafeteria was increased so that the sulfur hexafluoride concentration was halved in about 30 minutes. A similar, although less dramatic change occurred in the main area of the plant during the beginning-of-day (see Figure 4), lunch, and end-of-day movement into and out of the plant, when the effective rate of ventilation was increased so that the sulfur hexafluoride concentration was halved in less than 1 hour.

Figure 5 shows that the ventilation rate changes four times during the period between 5:00 and 9:00 in the evening. The early change is due to workers leaving the plant at the end of the shift. Ventila-

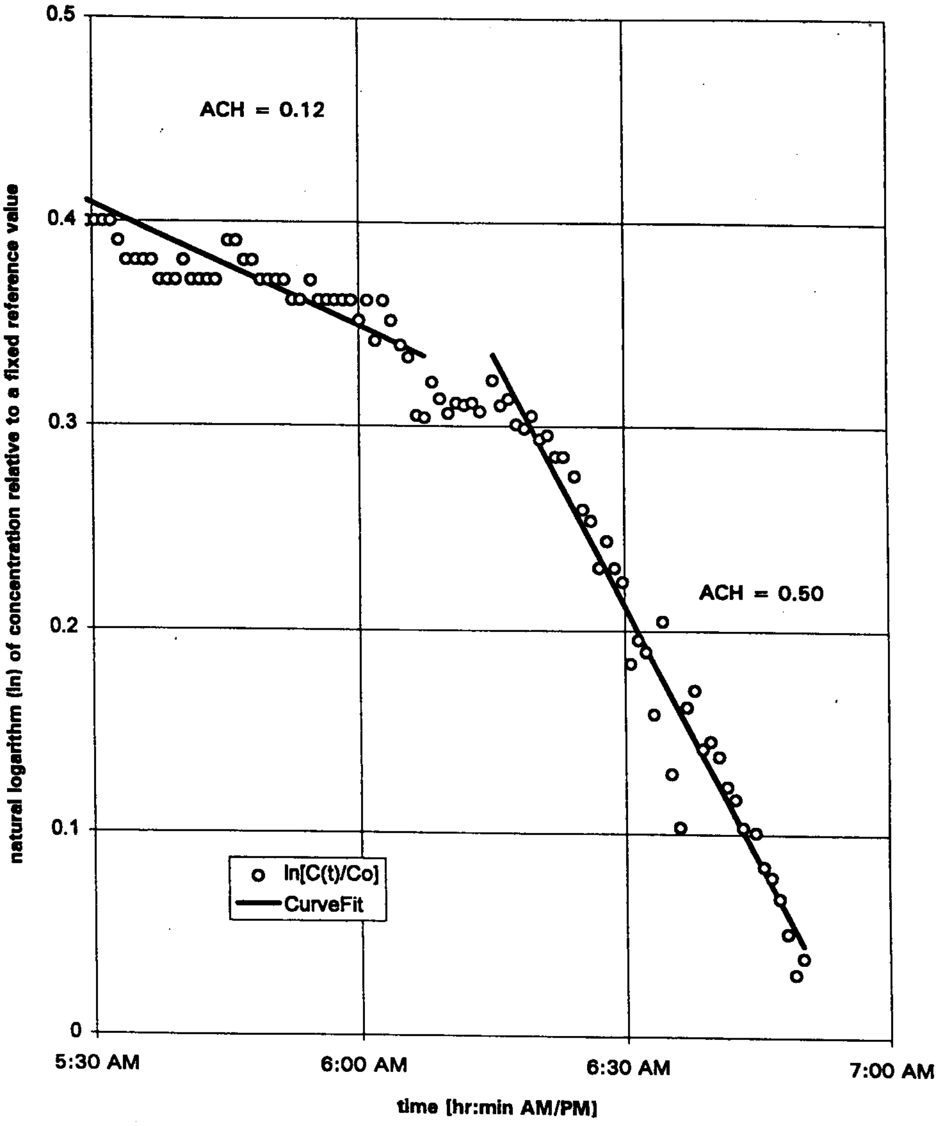

FIGURE 4. Concentration–decay plot showing ventilation rate changes at the beginning of the day as workers entered the plant.

tion rate changes later in the evening are probably due to the opening and closing of doors by cleaning staff, the use of compressed air by cleaning staff to blow down sewing machines, and the shutting down of AHUs.

Table 3 lists the air change rates that were determined from the concentration decay plots. The air change rates in the production area ranged from 0.23 to 0.29 ACH on the first day of measurement, and from 0.30 to 0.34 ACH on the second day. The ACH rates on the first day are indicative of worst-case conditions, since the outside air damper for AHU 6 was not open. The use of ceiling fans did not appear to affect air change rates. A small increase in the ACH rates was observed when the outside air damper for AHU 6 was open. The similarity in air change rates in the main production area indicates good air mixing.

Discussion/Conclusions

The ventilation configuration and related factors for this plant were favorable to the spread of airborne contaminants. Taking air from the plant floor into the air handlers located on the perimeter of the building, mixing some of this recirculated air with some outside air, and redistributing this air throughout the overhead region of the plant quickly and uniformly spread the tracer gas throughout the plant. The movement of the assembly lines, workers, raw materials, and finished products in the plant greatly contributed to the mixing, as did the thermal buoyancy due to numerous heat sources in the plant.

Minimizing the intake of outdoor air in such a large structure limits the removal rate of any contaminant. Since between 3 and 4 hours were needed to exhaust a volume of air equal to the volume of the plant, it is suspected that some of the *M. tuberculosis* organisms discharged into the workplace in the morning would still have been somewhere in the plant at the end of the shift.

Brief periods of higher contaminant removal rates occurred during breaks, at the beginning and end of the workday,

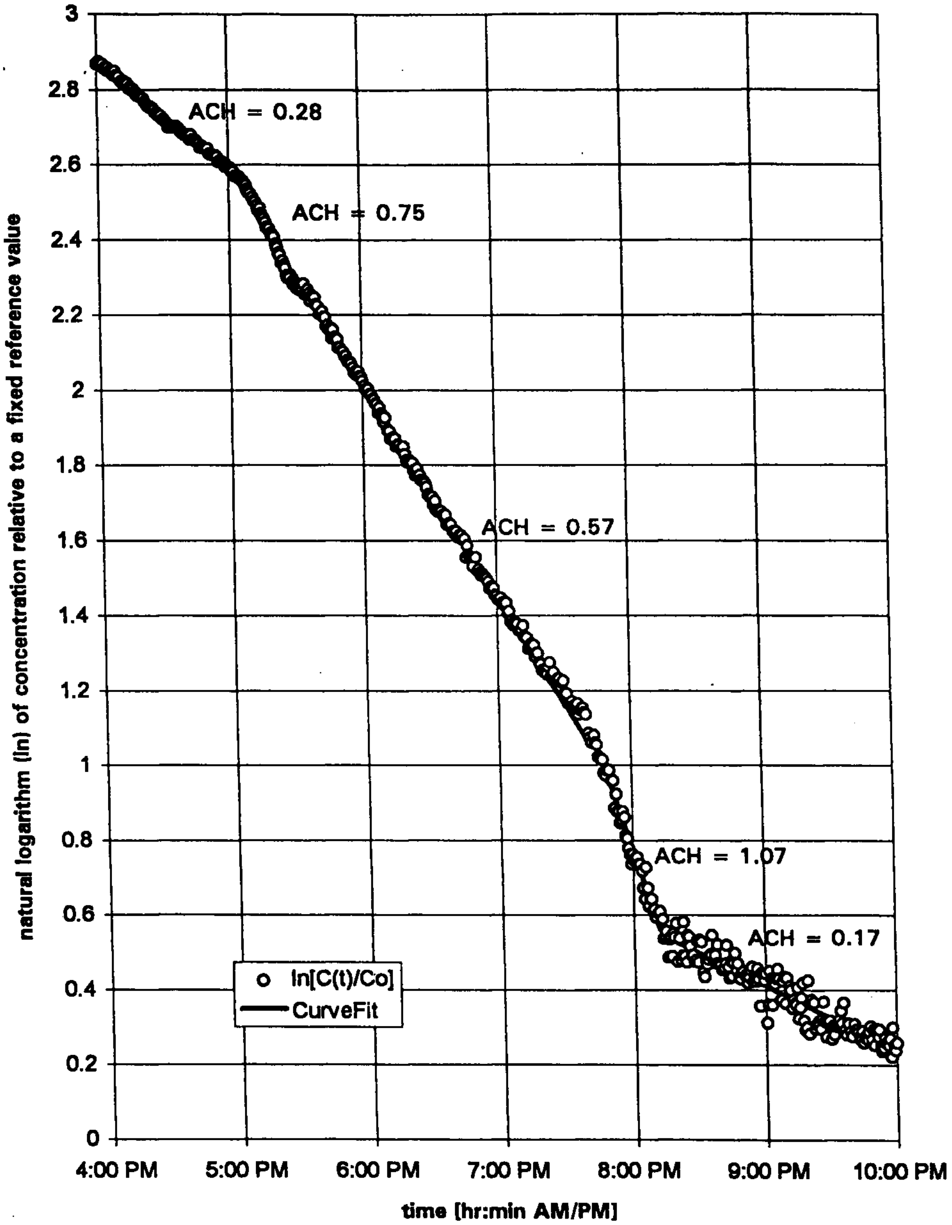

FIGURE 5. Concentration–decay plot showing ventilation rate changes throughout the evening.

and when raw materials were being received or finished products were being shipped. These periods of increased contaminant removal were probably due to the outside air brought into the building when the doors were opened and workers were entering and leaving the building. Similar reductions of contaminant concentrations occurred when the plant was being cleaned, presumably due to the use of compressed air from an outside source.

It is interesting to note that the air change rates determined from the tracer gas study (0.30 to 0.34 ACH) are very similar to the rate calculated based on the air flow measurements (0.36 ACH), given similar conditions (outside air damper for AHU 6 is open). Because the tracer gas analysis accounts for all infiltration, the similarity in rates indicates that there is very little infiltration of outside air through the building envelope, and further supports the conclusion that the air is well mixed. If significant sources of air infiltration existed, or there was poor air mixing, then a greater discrepancy in air change rates would be seen.

Based on the results of this evaluation, it is concluded that *M. tuberculosis* present in droplet nuclei would have spread quickly and uniformly throughout the plant and remained for hours before being removed from the air. Removal of *M. tuberculosis* would have been increased when the doors were opened, when workers were entering or leaving the plant, when raw materials or finished products were being loaded/unloaded on the loading dock, and during the evening cleaning. Other factors that may have influenced TB transmission include pro-

TABLE 3. Air Change Rates in Production Areas During Work Hours

		Air Change Rates (ACH)					
Day and Time[A]	Conditions	AHU 6	AHU 7	AHU 8	Corner Outside Office/Lobby	Between Movers 1 and 2	Between Movers 2 and 3
1/30/96							
Morning (7:00 to 11:15 a.m.)	Injection at 6:51 a.m.; circulating fans off; AHU 6 no outside air	0.27	—	0.29	—	0.28	0.28
Afternoon (12:30 to 5:00 p.m.)	Injection at 12:00 p.m.; circulating fans on at 12:10 p.m.; AHU 6 no outside air	0.27	0.23[B]	0.27	—	0.29	0.28
1/31/96							
Morning (7:30 to 11:30 a.m.)	Injection at 7:03 a.m.; circulating fans on; AHU 6 open for outside air	0.33	0.34	0.33	0.32	0.34[C]	0.34[C]
Afternoon (12:30 to 4:30 p.m.)	Injection at 12:10 p.m.; circulating fans on; AHU 6 open for outside air	0.32	0.30	0.32	0.32	0.32	0.31

[A]The times listed in the table represent the approximate time range during which the air change rate was calculated. Exceptions noted in the table.
[B]Time range during which the air change rate was calculated was 3:52 to 5:21 p.m.
[C]Time range during which the air change rate was calculated was 8:00 to 11:30 a.m.

longed infectiousness of the individual, virulence of the organism, and TB exposure outside the workplace. These factors were not evaluated in the NIOSH study, but were subsequently evaluated by state and local health departments and other groups within CDC. The results of these evaluations indicated that the outbreak strain was highly virulent, displaying a rate and extent of growth that exceeded those of virulent laboratory strains.[(12)]

Recommendations

Recommendations were made to improve general ventilation at this facility. It should be noted, however, that there are no ventilation guidelines for preventing infectious disease transmission in manufacturing settings such as this. Although increases in the amount of outside air supplied to the plant will aid in dilution of any contaminants, it is impossible to predict what, if any, impact the addition of modest amounts of outside air would have had on TB transmission at this facility.

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EDITORIAL NOTE: Teresa Seitz, Vince Mortimer, and Kenneth Martinez are with the Hazard Evaluation and Technical Assistance Branch of NIOSH. More detailed information on this evaluation is contained in Health Hazard Evaluation Report No. 95-0328-2630, available through NIOSH, Hazard Evaluation and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226; telephone: (800) 35-NIOSH; fax: (513) 533-8573.